New Asphaltene Nanoscience and Its Impact on Reservoir Characterization

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Crude oils consist of gases, liquids and solids, the asphaltenes. The gas and liquid constituents of crude oil are chemically well understood and their theoretical frame work can be satisfactorily treated by cubic equations of state. In contrast, the asphaltene have been grossly misunderstood precluding any theoretical treatment of asphaltene gradients in reservoirs. In recent years, asphaltene science has undergone a renaissance with many of the advances being subsumed in the "Yen-Mullins model" (named by Professor Zare at Stanford U.) which consists of asphaltene molecules, nanoaggregates and clusters of nanoaggregates. Various molecular diffusion and mass spectral measurements show that asphaltene molecular weights are ~750 (range 500-1000) Daltons. Molecular diffusion measurements originally established the predominance of (but not limited to) one polycyclic aromatic hydrocarbon (PAH) per molecule; this is now supported by laser mass spectral decomposition studies. This molecular architecture yields nanoaggregates with <10 aggregation number. High-Q ultrasonic studies were first to show that asphaltene nanoaggregates form at 10^{-4} mass fraction. SANS and SAXS studies show small stable asphaltene nanoaggregates; DC-conductivity studies support all these findings of the size and aggregation concentration. Clusters of nanoaggregates form at ~10^{-3} mass fraction as shown by a flocculation kinetics and other measurements.

With this nanoscience, the 'gravity' term is understood enabling our group to develop the industry's first equation of state for asphaltene gradients, the Flory-Huggins-Zuo EoS. This new science is being linked with new measurement technology Downhole Fluid Analysis to address reservoir complexities to optimize oil production. This new EoS has found enormous application in oil reservoirs accounting for asphaltene gradients in widely ranging fluids from condensate to heavy oil. Huge asphaltene gradients in height, over extended lateral distances of tens of kilometers are predicted with virtually no adjustable parameters matching field results. Sulfur XANES measurements on field samples confirm suitability of the FHZ EoS. Equilibration of reservoir fluids indicates reservoir flow continuity as proven is many case studies. Disequilibrium of reservoir fluids can often be treated with the FHZ EoS with a transient diffusive term. Several mechanisms of tar mat formation are now resolved addressing a long-standing enigma in the oil industry. Moreover, in a recent breakthrough, oil-water interfacial science has been shown to be consistent with the Yen-Mullins nanoscience model providing a way forward to investigate more challenging interfacial concerns. The combination of new asphaltene science new downhole measurement technology is producing an explosion of applications.